Neutrinos in Supersymmetry without R-Parity[1]

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Abstract.
We show how Bilinear R-Parity violation within the Minimal Supersymmetric Standard Model can solve the atmospheric and solar neutrino problems by generating naturally small and hierarchical neutrino masses, together with neutrino mixing angles consistent with experiments. The relation between collider and neutrino physics is emphasized.

It is well understood that the neutrino sector is a window to new physics beyond the Standard Model (SM). Several experimental results indicate that neutrinos oscillate and have mass [1]. Here we report on a supersymmetric solution to the atmospheric and solar neutrino anomalies in terms of a hierarchical neutrino mass spectrum [2,3]. A deficit of muon atmospheric neutrinos [4] can be explained by oscillations between muon and tau neutrinos with a mass squared difference

$$\Delta m^2_{atm} = m_3^2 - m_2^2 \approx 10^{-3} - 10^{-2}\,\mathrm{eV}^2\,, \tag{1}$$

and with near maximal mixing. Solar neutrinos detected in underground experiments are less than expected from theory, and this anomaly can be explained by oscillations between electron and muon neutrinos with a large mixing angle, solution favored specially by SNO results [5], and a squared mass difference

$$\Delta m^2_{sol} = m_2^2 - m_1^2 \approx 10^{-5} - 10^{-4}\,\mathrm{eV}^2\,. \tag{2}$$

In supersymmetry, one possible way to generate neutrino masses is via bilinear R-Parity violation (BRpV) [6], where bilinear terms, which violate R-Parity and lepton number, are added to the MSSM superpotential:

[1] Talk given by M.A.D. at High Energy Physics Workshop, Valdivia, Chile.

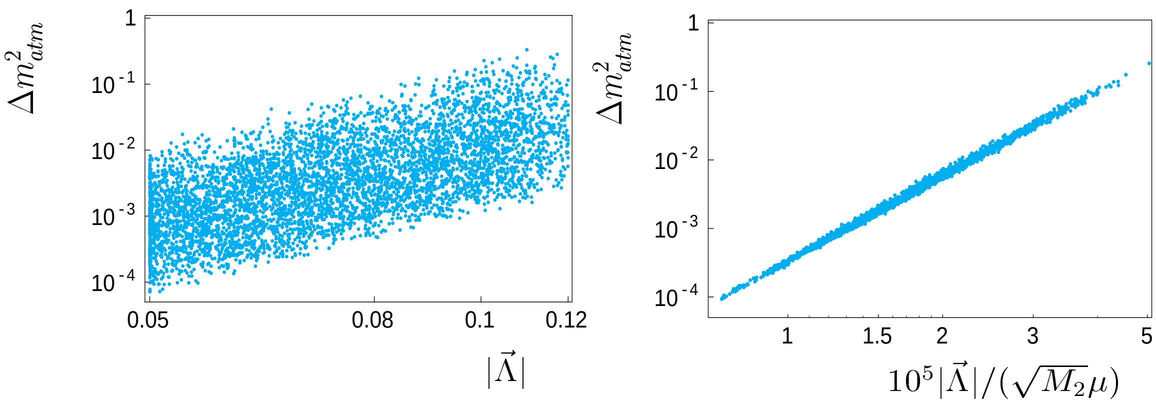

FIGURE 1. *Example of calculated Δm^2_{atm} as a function of (left) the alignment parameter $\vec{\Lambda}$ and (right), as function of $|\vec{\Lambda}|/(\sqrt{M_2}\mu)$.*

$$W = W_{MSSM} + \epsilon_i \hat{L}_i \hat{H}_2 \tag{3}$$

Their presence is motivated by models where R-Parity and lepton number are spontaneously broken by right handed neutrino vev's [7], or by models with horizontal symmetries [8]. These bilinear terms[2] induce sneutrino vacuum expectation values v_i and mixing between neutrinos and neutralinos. With a low energy see-saw mechanism, this mixing generates at tree level a mass to one neutrino, while the other two remain massless. This tree level neutrino mass satisfy $m_3 \sim |\vec{\Lambda}|^2$, where $\Lambda_i = \mu v_i + \epsilon_i v_1$, which are naturally small parameters in models with universal soft parameters at the GUT scale:

$$\Lambda_i \sim \frac{3h_b^2|\vec{\epsilon}|}{16\pi^2} m_Z \ln \frac{M_{GUT}^2}{m_Z^2} \tag{4}$$

Masses for the other two neutrinos are generated once we include the one-loop corrections to the neutralino/neutrino mass matrix.

In Fig. 1 we see the strong correlation between the Λ_i parameters and the atmospheric neutrino mass, which is generated by the tree level mass matrix:

$$\sqrt{\Delta m^2_{atm}} \approx m_3 \sim |\vec{\Lambda}|^2 / M_{SUSY} \tag{5}$$

On the other hand, in Fig. 2 we see the correlation between the solar mass and the ϵ_i parameters, which appear in the neutralino/neutrino mass matrix at one loop via couplings, showing that the solar mass is a genuinely one-loop effect. The main contribution comes from sbottom loops, and we have approximately:

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[2] Trilinear R-Parity violation, if present, also contribute to neutrino masses [9]

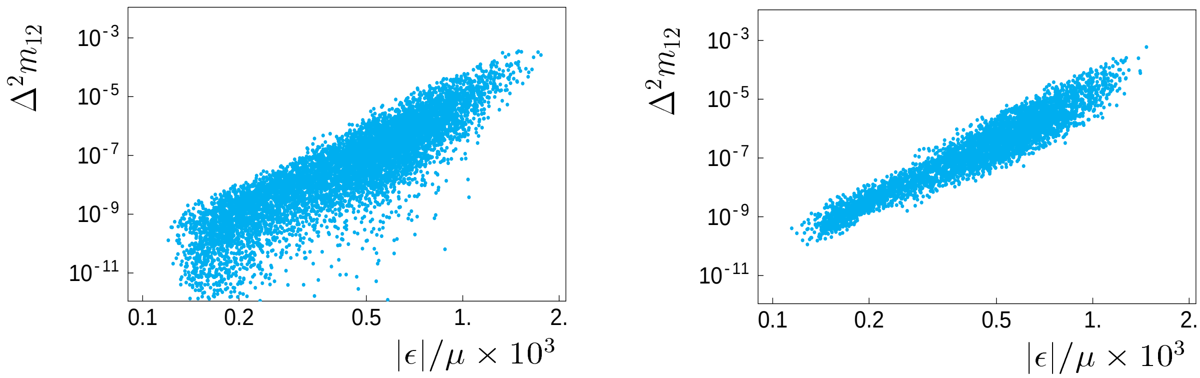

FIGURE 2. *Solar mass squared difference as a function of* $|\epsilon|/\mu$ *for* $\mu \leq 0$ *(left) and* $\mu > 0$ *(right).*

$$\sqrt{\Delta m^2_{sol}} \approx m_2 \sim \frac{3h_b^2|\vec{\epsilon}|^2}{16\pi^2}\frac{m_b}{M^2_{SUSY}} \ln \frac{M^2_{\tilde{b}_2}}{M^2_{\tilde{b}_1}} \,. \tag{6}$$

Maximal atmospheric and solar mixing angles can be obtained in this model relaxing exact universality. Maximal atmospheric angle is obtained when

$$\tan\theta_{23} = \Lambda_\mu/\Lambda_\tau \approx 1 \tag{7}$$

and the Chooz constraint $\sin^2\theta_{13} < 0.045$ [10] can be satisfied taking

$$|\tan\theta_{13}| = |\Lambda_e|/\sqrt{\Lambda_\tau^2 + \Lambda_\mu^2} \ll 1 \,. \tag{8}$$

Finally, after relaxing exact universality of soft mass parameters the maximal mixing can be achieved, for example, taking

$$\epsilon_e \ll \sqrt{\epsilon_\tau^2 + \epsilon_\mu^2} \,. \tag{9}$$

A very interesting property of the BRpV model is that neutrino physics is closely related to collider physics in a measurable way. As mentioned before, mixing between neutrinos and neutralinos allow the generation of neutrino masses through a low energy see-saw mechanism. The atmospheric mass depends mainly on the Λ_i parameters, and the same parameters control the mixing between gauginos and neutrinos. In this way, the neutralinos will have decay channels into leptons with couplings that depend on the Λ_i. In the case of the lightest neutralino, lepton number and R-parity violating decays branching ratios sum up to 100%, because R-Parity conserving decays are

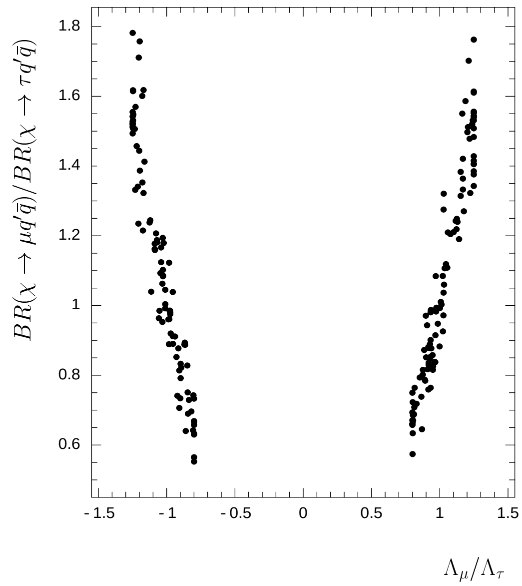

FIGURE 3. *Ratio of branching ratios for semileptonic LSP decays into muons and taus: $BR(\chi \to \mu q'\bar{q})/BR(\chi \to \tau q'\bar{q})$ as function of Λ_μ/Λ_τ.*

closed. Since neutralino couplings to leptons will depend on the Λ_i, measurements on branching ratios will give information on neutrino physics and vice versa. In Fig. 3 we plot a ratio of semileptonic branching ratios of the lightest neutralino decays into muons and taus. It is evident from the figure the correlation between the former ratio and Λ_μ/Λ_τ, quantity that controls the atmospheric mass scale.

In summary, lepton number and R-Parity violating bilinear terms in supersymmetric models can generate hierarchical neutrino masses and bimaximal mixings, and thus explain the solar and atmospheric neutrino anomalies. This model is highly predictive, introducing very few extra parameters to the MSSM, while predicting three masses and three mixing angles. This model has the additional interesting feature of connecting neutrino physics with collider physics. For example, measurements on branching ratios of neutralino decays give information on neutrino parameters and vice versa.

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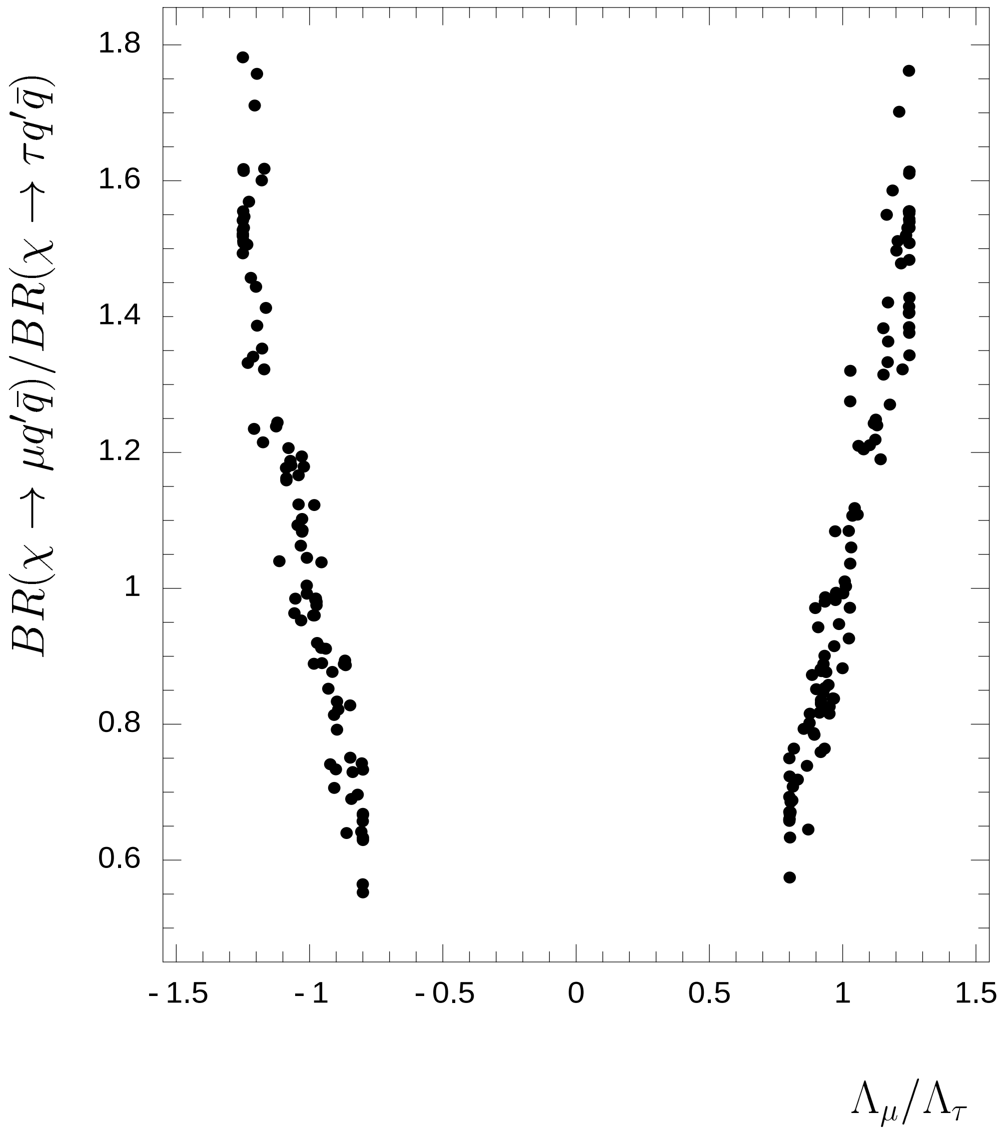

1.8
1.6
1.4
1.2
1
0.8
0.6
- 1.5
- 1
- 0.5
0
0.5
1
1.5
$BR(\chi \to \mu q'\bar{q})/BR(\chi \to \tau q'\bar{q})$
Λ_μ/Λ_τ